"Data Acquisition Unit" Requirements and Specifications

CERTS Project Final Report for FY 03

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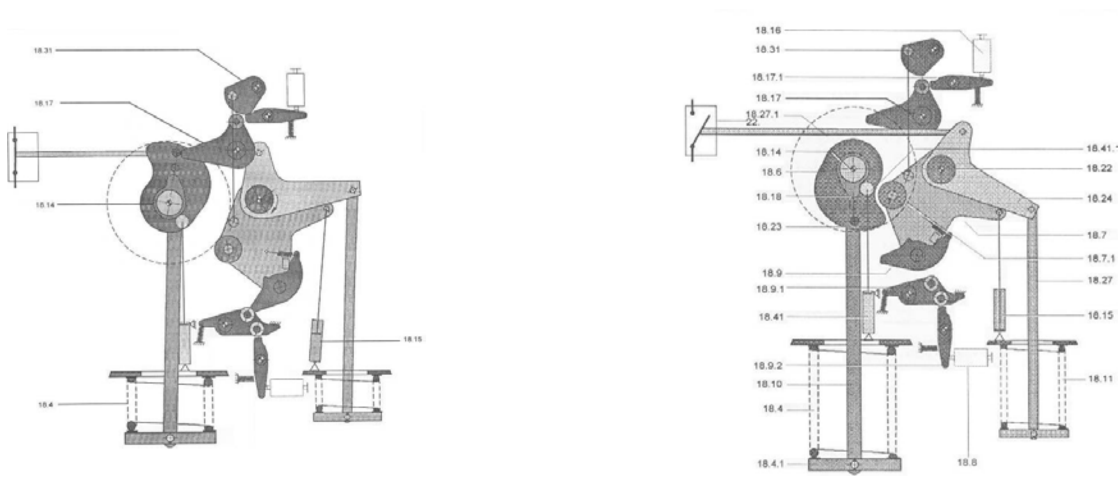
Outline

1. BACKGROUND

1.1 Circuit Breaker

Circuit breakers are electro-mechanical devices that should, working together with protective relays, provide distribution of electrical energy but also prevent damages to certain parts of the network during fault conditions. Mechanical structure of the circuit breaker is shown in Figure 1-1.



a) Closed state **b) Open state**

Figure 1-1: Mechanical structure of the Circuit breaker

During normal operating mode, circuit breaker can be found in two different states: Open or Closed state. Circuit breaker is in a closed state when there is no fault present on the transmission line, while open state occurs when fault is present somewhere on the line or if there is a maintenance outage.

Figure 1-2 shows a circuit breaker during repair. Figure 1-3 shows inner side of the breaker. Connector, which is important for our “Data Acquisition Unit”, is marked and can be spotted.

Figure 1-2: Circuit breaker

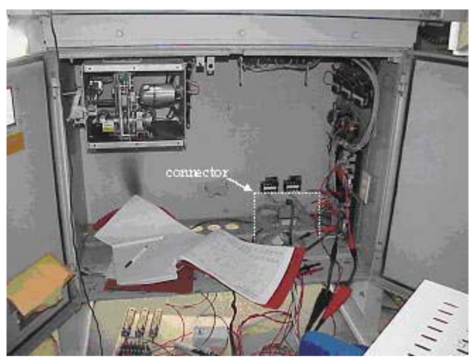


Figure 1-3: Inner side of the circuit breaker

Connector marked in Figure 1-3 provides control signals generated either at protective relay, or at circuit breaker itself. There is going to be much more talk about these signals in the next paragraph, but for now only location of the connector is mentioned. Location itself is going to be very important for design of the “Data Acquisition Unit”, since connector resides inside of the metal box, where electromagnetic noise is very high. This fact has to be considered during system design if we want the breaker to work properly even in such severe electromagnetic conditions.

There are also several types of breakers (transmission breaker, distribution breaker), depending on current and voltage level they are supposed to interrupt.

1.2 Electrical characteristics of a circuit breaker

There are 15 electrical signals generated during either tripping or closing of the breaker. 11 of them are analog, while other 4 are status signals. The most important signals are Trip Event and Close Event. These signals, generated by the protection relay, initiate some other signals (some generated during tripping, some during closing only), and as a result tripping or closing of the circuit breaker occurs. Figure 1-4 shows simplified control circuit of the circuit breaker.

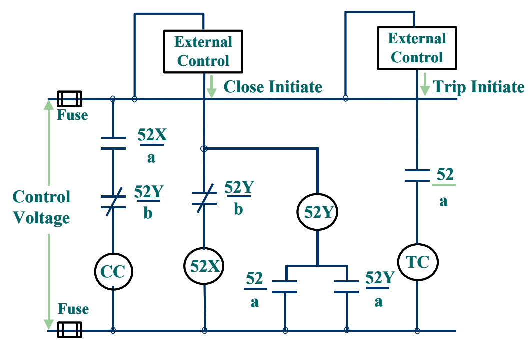
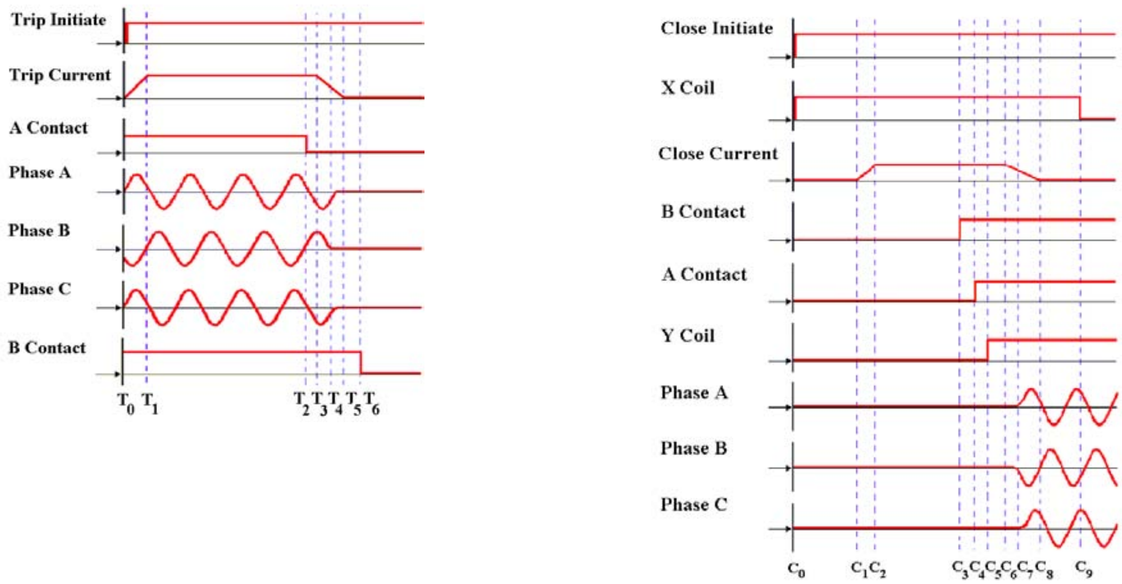


Figure 1-4: Control circuit of the circuit breaker

Signals, not mentioned in the Figure 1-4, which change their values as a result of tripping or closing are:

1. Control DC – analog signal
2. Light wire – analog signal
3. Yard DC – analog signal
4. A contact – analog signal
5. B contact – analog signal
6. Close coil current – analog signal
7. Trip coil current #1 – analog signal
8. Trip coil current #2 – analog signal
9. Phase A current – analog signal
10. Phase B current – analog signal
11. Phase C current – analog signal
12. Close event – status signal
13. Trip event – status signal
14. X coil – status signal
15. Y coil – status signal

Figure 1-5 shows waveforms of signals, which change their values during tripping and closing, respectively. Some of the signals change their values during both tripping and closing (A contact, B contact), while some of them change as a result of either tripping or closing (Trip current, Close current).



a) Trip Event **b) Close Event**

Figure 1-5: Waveforms of circuit breaker signals

As it can be seen from the figure above, tripping results in sinusoidal signals on phases A,B and C dissapearing. On the opposite, as a result of closing, phases are switched on again (sinusoidal waveform are present).

Waveforms of signals mentioned above are important because after analyzing them, it can be determined whether breaker works properly or not.

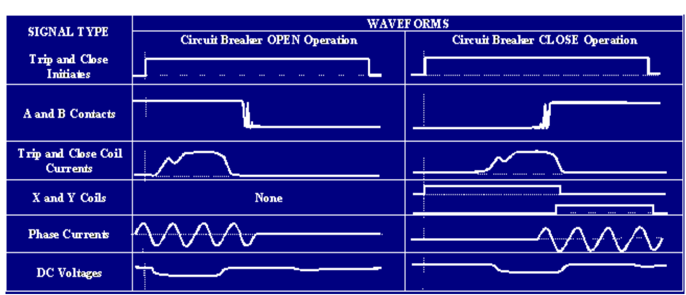


Figure 1-6: Performance characteristics of circuit breaker

All of the signals mentioned above are voltage signals, even though some of them represent currents (Trip current, Close current). Voltage signals, which represent currents, are taken from shunts. Figure 1-7 shows voltage levels of both voltage signals and current signals after measuring voltage drop across a shunt.

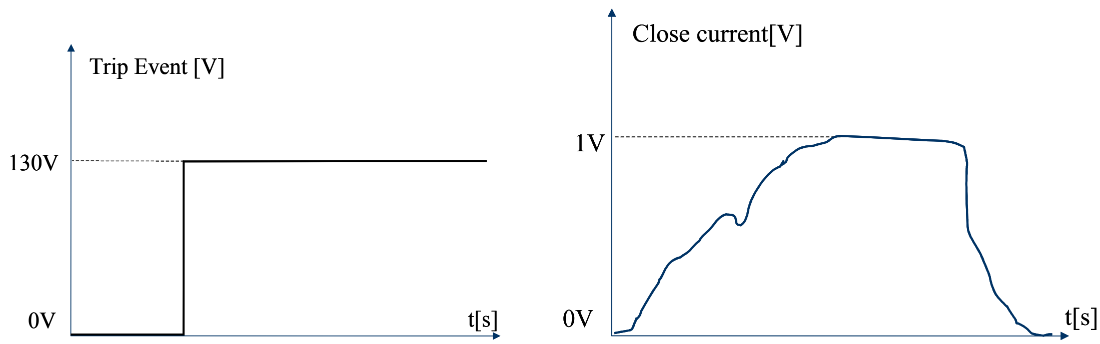
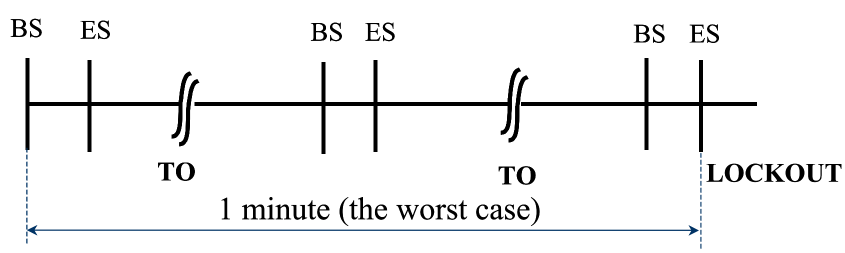


Figure 1-7: Voltage levels of circuit breaker signals

Observing the shape of the signals will be very important when we reach the design specifications.

1.3 Tripping and Closing sequences



- BS -- beginning of sequence
- ES – end of sequence
- TO – time out

Figure 1-8: Tripping and closing sequences

Figure 1-8 shows sequences occurring as a result of fault present somewhere on a transmission line. What actually happens is that sequences are initiated in order to determine whether fault, which occurred, is still present or not after multiple reclosing takes place. First sequence usually consists of trip event (fault is there), close event (to see if the fault is gone) and trip event once more (if fault is still present). After that sequence there is time a out which lasts from 13 to 25 seconds and its purpose is to wait for fault to end in a certain period of time (depending on the type of breaker). After the time out, closing of the breaker is performed. If fault still persists another tripping is initiated. Once more, time out and sequences of closing and tripping are repeated and if fault is still there, lockout is taking place. That means that there will be no more attempts to close the breaker, since fault is, obviously, not temporary.

The length of sequences and time outs depends on the type of the breaker. Worst case (considering recording of the signal which will be our main task) is permanent fault on a distribution breaker, when 1 minute elapses before a lock-out.

During the sequences, all of the 15 signals change their states. Some of them change state as a result of Trip Event signal change, some of them as a result of Close Event signal change. length of sequences is very short (the whole sequence last around 0.5 seconds), so that fact should also be considered while designing the system.

2. REQUIREMENTS

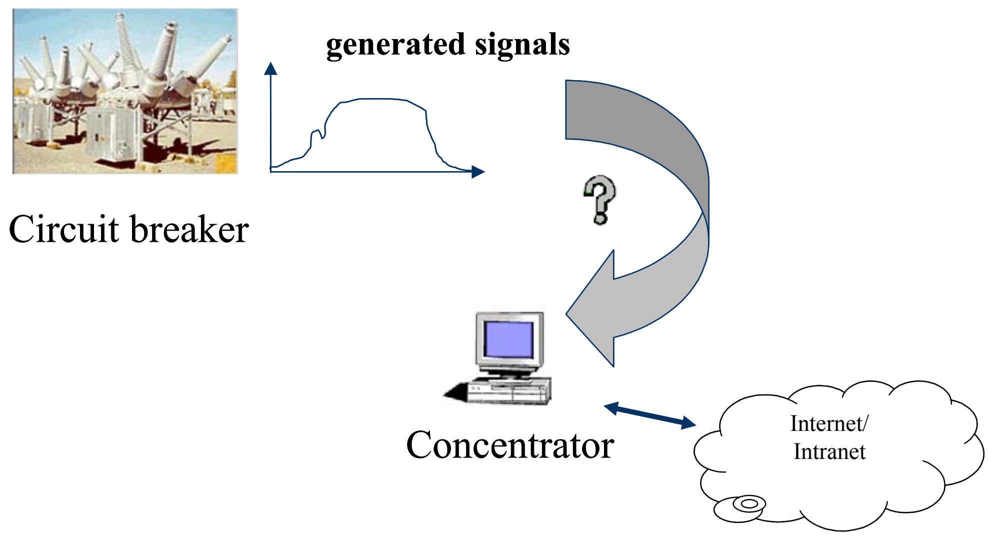


Figure 2-1: Main task of the "Data Acquisition Unit"

Figure 2-1 above shows the main task of our data acquisition unit. There are signals generated during sequences of tripping and closing (shown in Table 2-1), which should be recorded, and wirelessly transferred to a concentrator PC, from where data can be easily transferred further over the Internet (or LAN). The Concentrator PC is usually located in a control house at the substation.

So, there are three main subtasks included in the main task:

- **Perform data acquisition of 15 signals (11 analog and 4 status) and record sequences of tripping and closing;**
- **After capturing sequences, create files according to a COMTRADE file specifications;**
- **Wirelessly send files to concentrator PC.**

Table 2-1: Circuit breaker signals with descriptions [1]

Signal Name	Channel	Type	Analog or Status	Nominal Range	How it relates to the circuit (Fig 1-4)
Control Voltage	Voltage	Contact	A	125V ± 15V	Provides Pos/Neg voltage for contacts
Light Wire	Voltage	Contact	A	125V ± 15V	ON/OFF Indicator
Aux. Contact B	Voltage	Contact	A	125V ± 15V	Establishes connection from Light to Neg
Yard DC	Voltage	Contact	A	125V ± 15V	Runs CB motor
Aux. Contact A	Voltage	Contact	A	125V ± 15V	Indicates breaker status
Close Coil Current	Current	Shunt	A	<10A	Used to physically close the CB
Trip 1 Coil Current	Current	Shunt	A	<10A	Used to physically open the CB
Trip 2 Coil Current	Current	Shunt	A	<10A	Used to physically open the CB
Phase A Current	Current	Shunt	A	~5A	Indicates breaker status
Phase B Current	Current	Shunt	A	~5A	Indicates breaker status
Phase C Current	Current	Shunt	A	~5A	Indicates breaker status
Close Initiate	Event	Contact	S	125V ± 15V	Initiates a close operation
Trip Initiate	Event	Contact	S	125V ± 15V	Initiates a trip operation
'X' Coil	Event	Coil	S	125V ± 15V	• Closes all 52X contacts •Establishes a path from POS to 52CC
'Y' Coil	Event	Coil	S	125V ± 15V	•Opens all 52Y contacts •Interrupts 52CC and X coil currents

[1] Note: More details about theory of circuit breaker operation can be found in document "Automated Circuit Breaker Analysis", A Thesis by Christopher Donald Nail

Our unit should reside near the circuit breaker, and monitor 15 signals, especially the Trip Event signal which indicates that fault is present somewhere on the transmission line and initiates beginning of the tripping and closing sequences. When trigger occurs (Trip Event signal goes from low to high voltage level) the subsequent sequences have to be recorded before a lockout occurs. Recorded events have to be stored in COMTRADE files (files which comply with COMTRADE standard specification), and in that format transferred to a concentrator PC.

Sampling rate has been selected to be 5760 Hz because application for analyzing recorded data was designed for that sampling rate. Other sampling rates may be selected as well.

NOTE: Since application for analyzing recorded data needs exact waveforms of all signals (analog and status signals), all 15 signals are recorded as analog signals, even though four of them are status signals!

Figure 2-2 shows one particular waveform of the status signal and the way it is written in COMTRADE file.

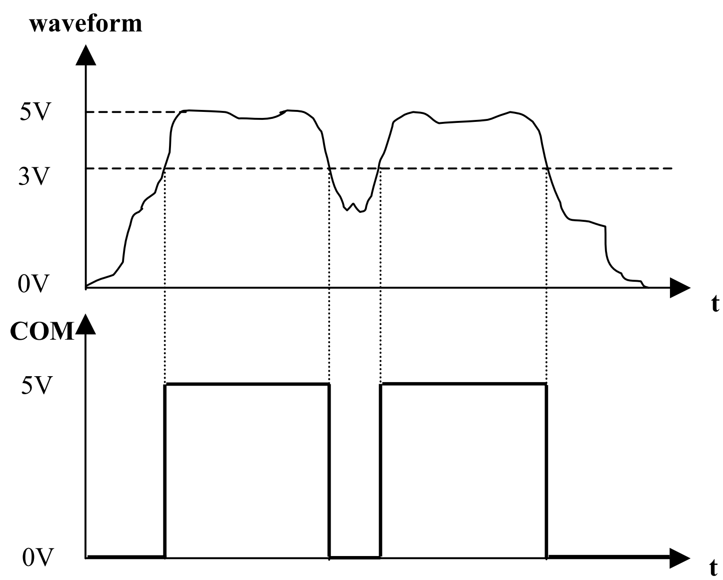


Figure 2-2: Waveform and corresponding COMTRADE record of status signal

Distance between concentrator PC and any circuit breaker in the field, doesn't exceed 200m. That is also very important issue which has to be considered during design of DAU. Requirements are summarized in Table 2-2.

Task Number	Task Description
1	Monitor 15 signals generated at circuit breaker
2	When status on 'Trip Event' Signal changes, start recording sequences before lock out
3	Sampled data store in 3 files according to COMTRADE file specification[2]
4	Transfer recorded files to concentrator PC from where they could be distributed further to applications responsible for data analysis

Table 2-2: DAU Requirements

[2] *IEEE Std C37.111-1999* (Revision of IEEE Std C37.111-1991)
IEEE Standard Common Format
for Transient Data Exchange (COMTRADE) for Power Systems

3. DESIGN SPECIFICATIONS

3.1 Modularity of DAU

To a flexible design of DAU, we have used a modular approach. Modular approach allows us to create separate modules of DAU. Each of them should be completely independent from the others, while integration of all modules solves the problem of recording sequences and transferring them to another applications.

Considering nature of the signals (their voltage levels) and requirements, there are three separate modules of DAU:

- **Module for signal conditioning and galvanic isolation (SCI module);**
- **Module for data acquisition and COMTRADE files creation (DA module);**
- **Module for wireless transfer of recorded data (WT module).**

Modules are shown in the Figure 3-1.

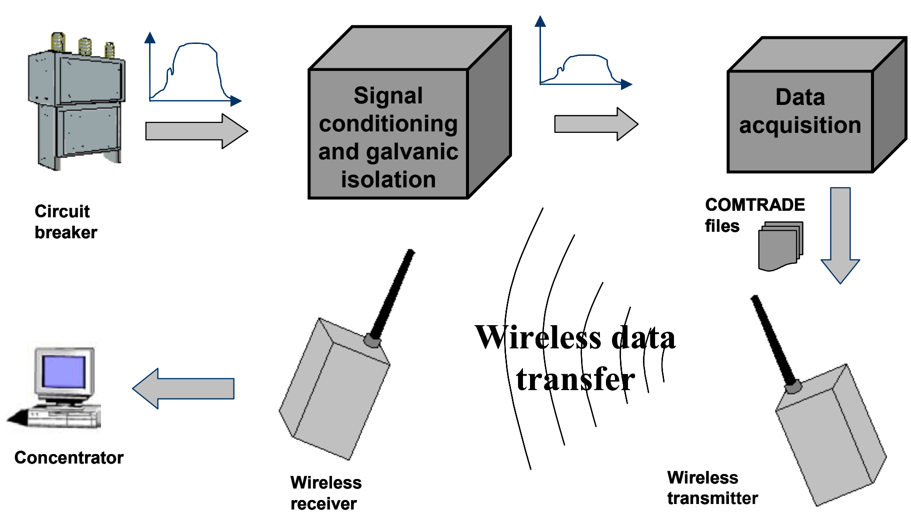


Figure 3-1: Modules of DAU

3.2 SCI module

SCI module has to provide appropriate voltage levels for data acquisition. As we mentioned in paragraph 1.2 (Electrical characteristics of a circuit breaker), voltage levels of signals at circuit breaker are either 130VDC or 1 VDC. Since voltage range of the signals at the input of the DA module has to be (-5,+5)V, SCI module should provide that. Obviously, SCI module should have adjustable gain for all 15 channels, so user can determine which gain to use with which signal at the input of the module. For example, if signal at the channel 6 is “Trip current” signal, user should adjust gain 5 to that channel, in order to provide 5V voltage level at the output of SCI module (because current signals from CT’s have amplitude of 1V and DA module requires 5V at the input).

Beside that, another purpose of SCI module is to provide galvanic isolation of the signals at the input. With isolation provided, faults at the input of SCI module won’t damage components at the output (DA module). Functionality of SCI module is shown in Figure 3-2.

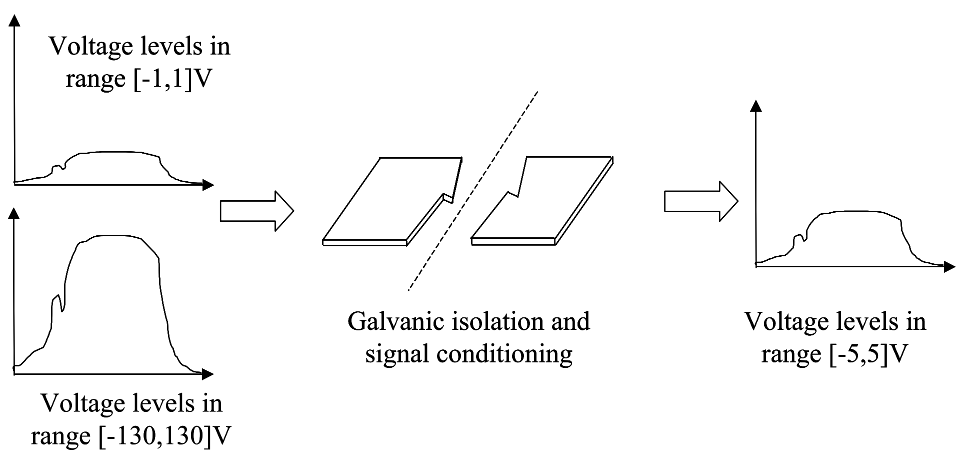


Figure 3-2:Functionality of SCI module

3.3 DA module

DA module consists of a processor board and a board for data acquisition. While the board for data acquisition has to provide desired sampling rate (5760 Hz), the processor board should provide efficient system resources management and also management of the data acquisition board itself. Figure 3-3 shows functionality of DA module. DA module has to provide sampling, monitoring and, when the fault is present, recording of signals from all 15 channels. Although Figure 3-3 shows only one signal, all 15 signals have to be included in COMTRADE files.

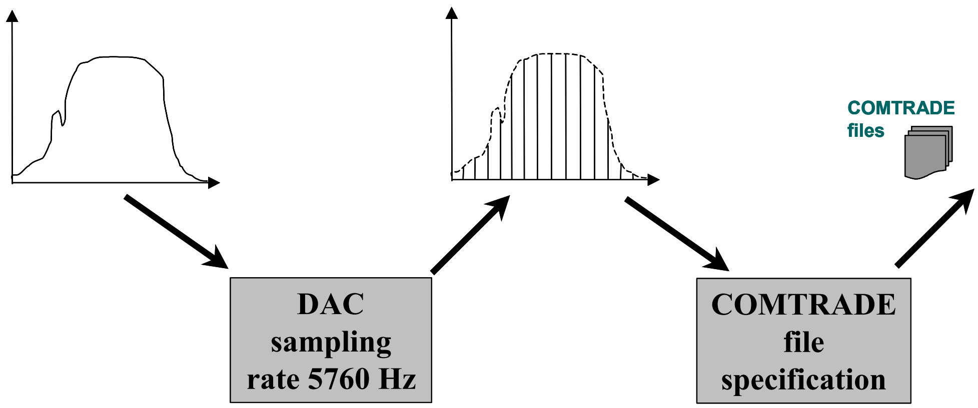


Figure 3-3: Functionality of DA module

3.4 WT module

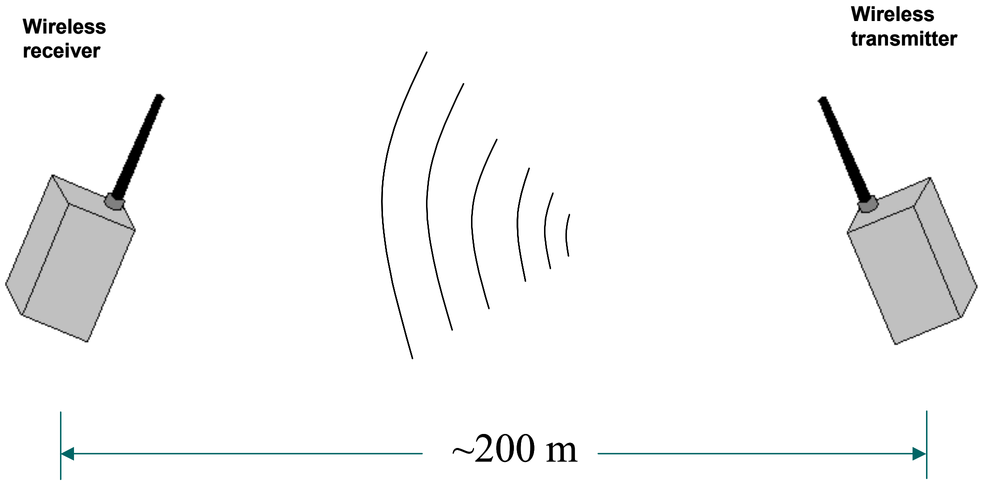


Figure 3-4: Functionality of WT module

Figure 3-4 above shows functionality of WT module. Every wireless system capable of transmitting data over 200m would be appropriate for DAU. Transfer protocol for data transfer has to be established, providing that concentrator PC receives valid COMTRADE files from DAU.

4. TESTING

4.1 Lab testing

4.1.1 Module testing

1) SCI module testing

The Board can operate in two different modes: amplifying with a gain bigger than 1 ($A_v > 1$) and amplifying with a gain lower than 1 ($A_v < 1$). Two modes are distinguished by jumpers. Mode with $A_v > 1$ is used when the input signal comes from current transformer and thus it is of lower amplitude than needed for data acquisition (amplitude is 1V). On the opposite, when the applied signal is a voltage signal of higher amplitude (130 VDC), the gain has to be smaller than 1 in order to provide the voltage level of 5V necessary for data acquisition. If input signals represent current signals, jumpers should be disconnected, and connected if input signals represent voltage signals.
For simulating current signals, signal generator was used. It can generate signals of amplitude up to 15 V, which was more than enough. For simulating voltage signals from a circuit breaker, AVO test-set has been used. Signal waveforms have been made using "ATP draw" software and reproduced using AVO test-set.
Prior to testing some minor changes have been made on the board. When the board has been designed, the same power supply has been used for both sides of the circuit (high voltage and lower voltage side). Since we need complete galvanic isolation, two completely separate power supplies should be used, and thus all integrated circuits should use appropriate power supply. That is why power lines onboard were cut and new power lines are made. Results of the testing are shown in Figures 4-1 and 4-2.

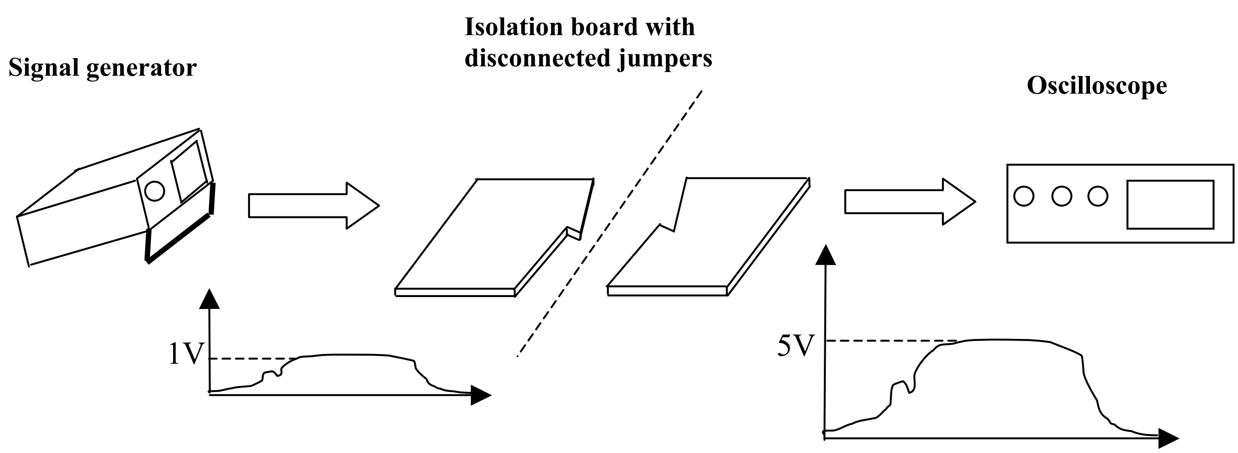


Figure 4-1: Signal amplifying with disconnected jumpers

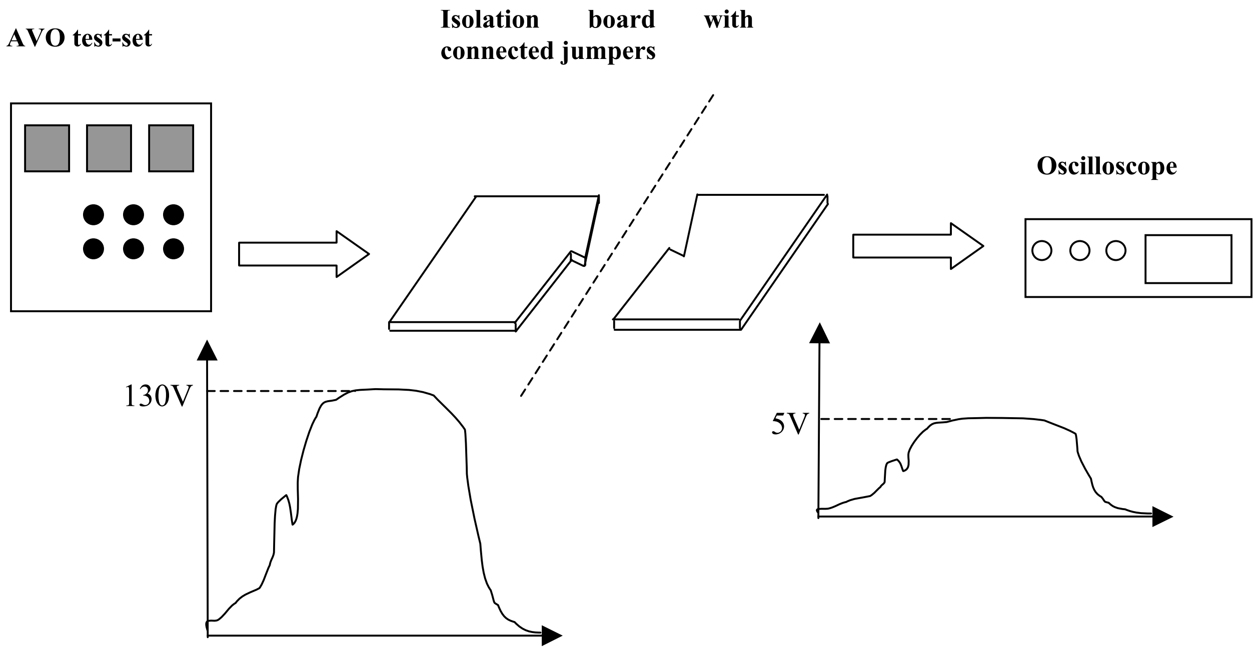


Figure 4-2. Signal amplifying with connected jumpers

As it can be seen from figures 4-1 and 4-2, signals at the input and output of the board matched each other in waveforms. They only differed in the amplitude. With disconnected jumpers, the amplitude of the signal at the output was 5 times higher than the signal amplitude at the input. With connected jumpers, signal amplitude at the output was 26 times lower than at the input. Besides, the signal conditioning and galvanic isolation have been performed using Burr-Brown's isolation amplifier.

The behavior of the board with different frequencies of input signal has been determined. Results have shown that isolation board behaves like a low-pass filter with cut-off frequency of 1.8 kHz (Figure 4-3). Because of that, the needed sampling rate of 5760 Hz may be implemented. Negative slope of the transfer function at frequencies above 1.8 kHz is –40dB/decade, meaning that signals at frequency of 2 kHz are repressed almost totally.

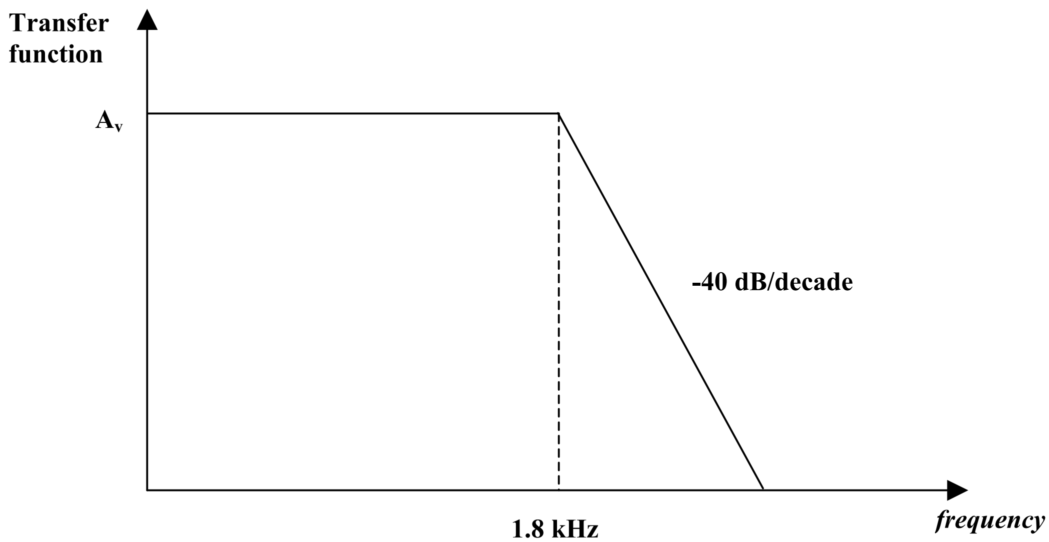


Figure 4-3: Frequency domain analysis of the isolation board

2) DA module testing

Main tasks of the DA module are to perform data acquisition of output signals from SCI module and then create COMTRADE files according to sampled signals. There are 15 signals to be sampled, sampling rate should be 5760 Hz and the length of recorded signals should be 1 minute. Input signals for application (output signals from SCI module) have to be within [-5,+5] V range. Assumed that isolation board is adjusted well, this is going to be provided.

Since this application was tested separately from other modules, input signal with voltage level of 5V has been generated using signal generator.

The application works as follows: it first waits for signal called Close Event (at channel number 12) to become active. That means that after connecting the whole system with the circuit breaker (which was previously de-energized) power supply is applied again. After reenergizing of the system application goes into a normal mode of operation waiting for Trip Event signal (at channel number 11) to become active (meaning that falt is present). After that, samples from all 15 channels are being recorded during 1-minute time interval. At the end, three files should be made according to COMTRADE file specification (header, configuration and data file).

For testing purposes, pulses have been generated using signal generator. First, pulse has been applied to channel number 12 (simulating Close Event which will bring application into normal mode of operation). After that, pulse has been applied to channel number 11 (simulating Trip Event which will initiate COMTRADE file recording).

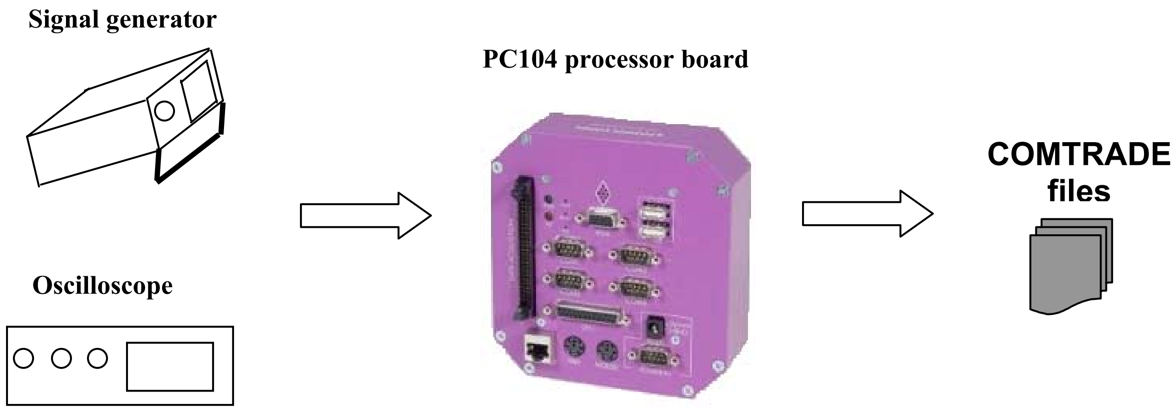


Figure 4-4: Testing the application using signal generator

Waveforms of generated signals were observed by oscilloscope and they completely matched recorded data from COMTRADE file. The time information about tripping and the first sample stored in data COMTRADE file, which should be included in configuration file, also matched the time moments when mentioned events had happened.

3) WT module testing

File transfer over a distance of 200m couldn’t be performed in the lab, so only a file transfer between DAU and computer (around 10 meters far apart) was performed. Files were sent and received after approximately 25 minutes. Transfer lasted that long because data file was relatively big (around 13MB).

4.1.2 DAU testing

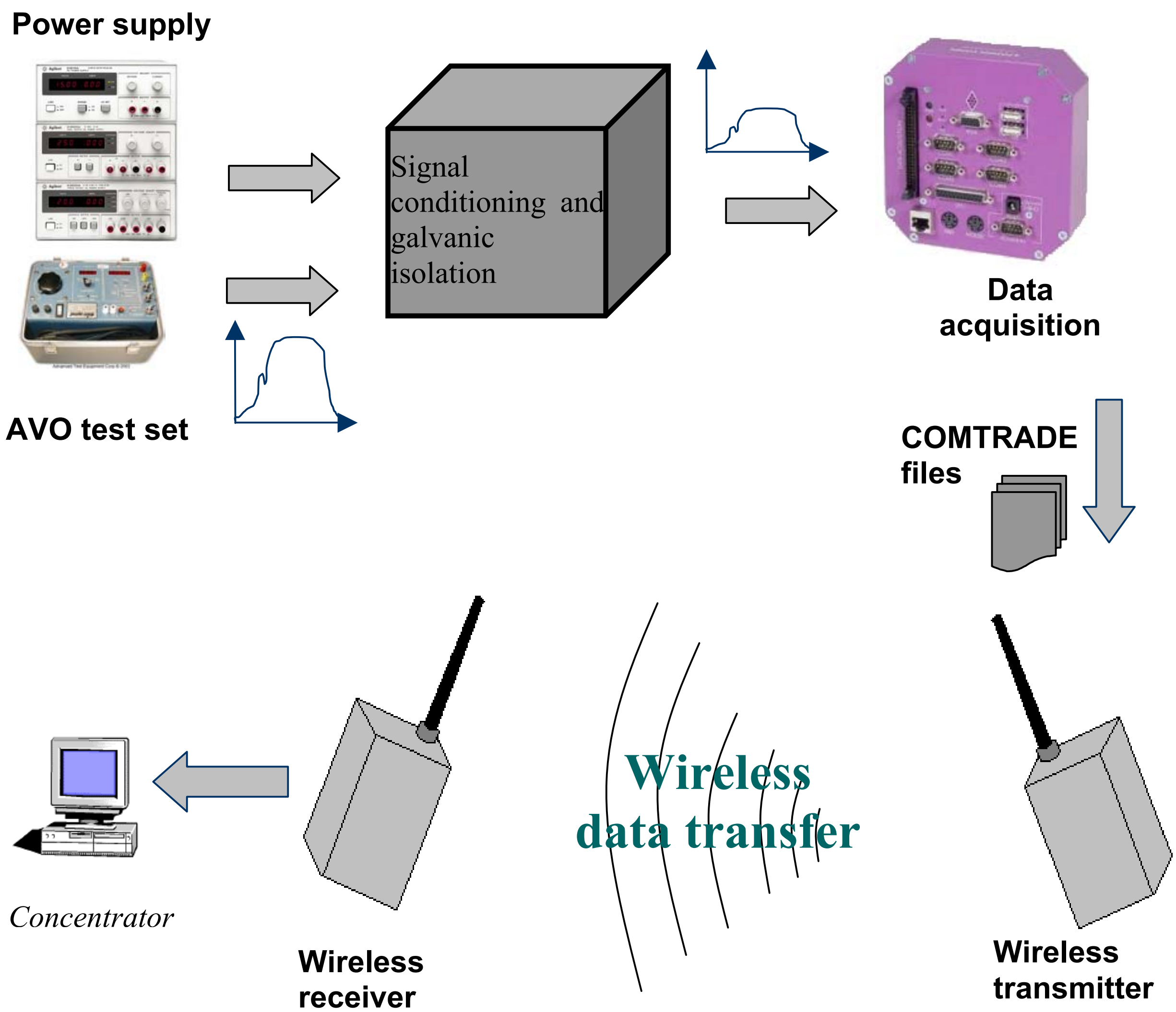


Figure 4-5: Components used for testing

Testing was performed using devices from the figure 4-5 above. AVO test-set is used to simulate signals from the circuit breaker (high voltage signals with voltage levels of 130VDC). Two power supplies had to be provided. First was for components in front of the integrated circuit for galvanic isolation, and second for components at the low voltage level side (after galvanic isolation). That is necessary if we want a complete galvanic isolation (with completely isolated circuits on both sides of the ISO122P isolation chip).

The Board for signal conditioning and galvanic isolation, with given power supplies, provides signals within desired voltage range needed for data acquisition. After conditioning and isolation, data acquisition is performed, and recorded data file is sent (together with the header and configuration file) to the concentrator PC. Application running at the concentrator PC receives the three files (for single event recorded) and saves them on a local hard drive. After receiving the files, concentrator polls next DAU, but since we had only one DAU available, instead of polling another DAU, the same DAU was asked for new files recorded.

The most important part of testing was to simulate signals from the circuit breaker. Problem was to generate signal of 130 VDC, which would be conditioned and sampled afterwards. For that purpose, AVO test-set has been used. It provides output of up to 200VDC with enough current capacity according to the input impedance of the board for signal conditioning and galvanic isolation. Signals generated with AVO test-set had waveforms shown in Figure 4-6.

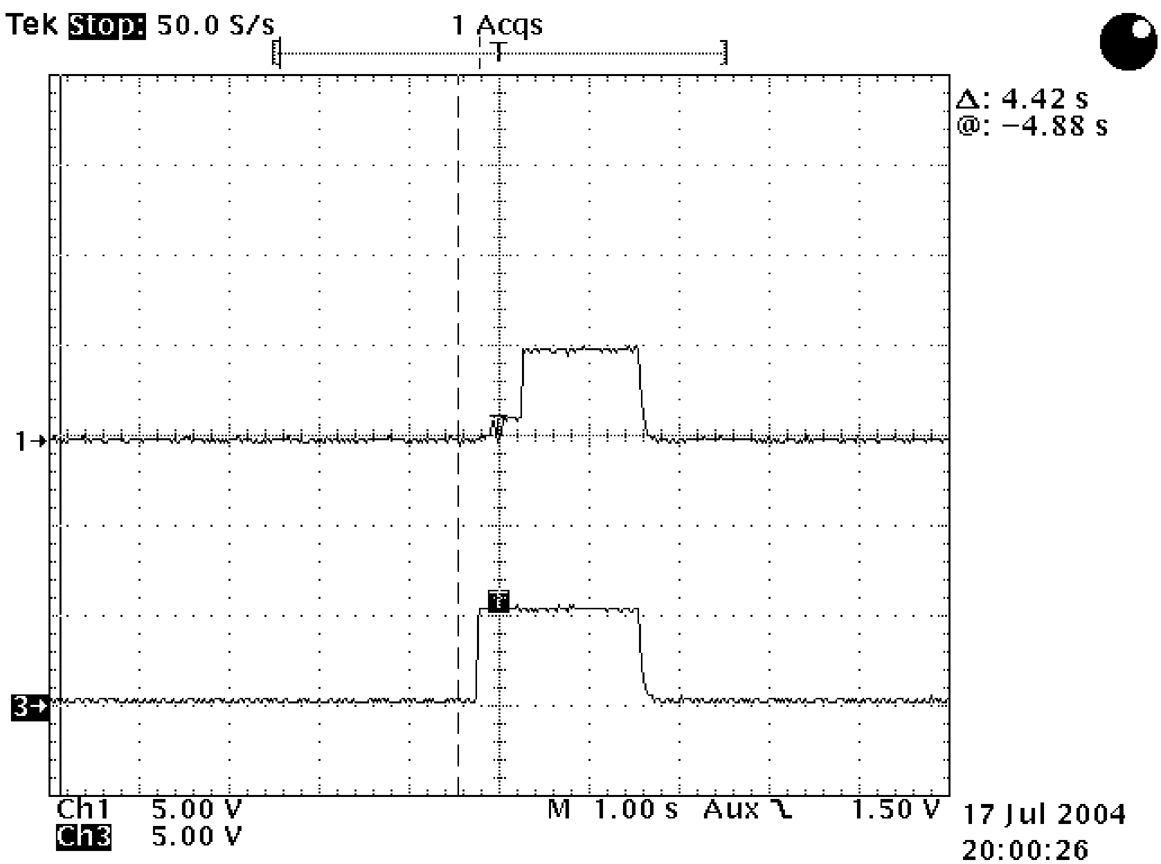


Figure 4-6: Waveforms of "Trip Event" and "Close Event" signals recorded by oscilloscope

Signal at channel 3 is “Close Event”, and the other one is “Trip Event”. Signals are recorded at the output of the board for signal conditioning and galvanic isolation. That can be noticed if voltage levels of the signals are observed. Even though the signals of 130VDC are brought to the input of the board, signal levels at the output are inside the (-5,+5)V range. Signals recorded are also isolated from the high voltage level signals at the input.

Signal at channel 3 (of the oscilloscope) is used as “Close Event” signal, because it made transition from 0 to 5V (from 0 to 130V) before the signal at channel 1. After performing AD conversion, recording COMTRADE files, and performing wireless data transfer of the files, “Relay assistant” software was used to reproduce waveforms of the signals recorded by DAU.

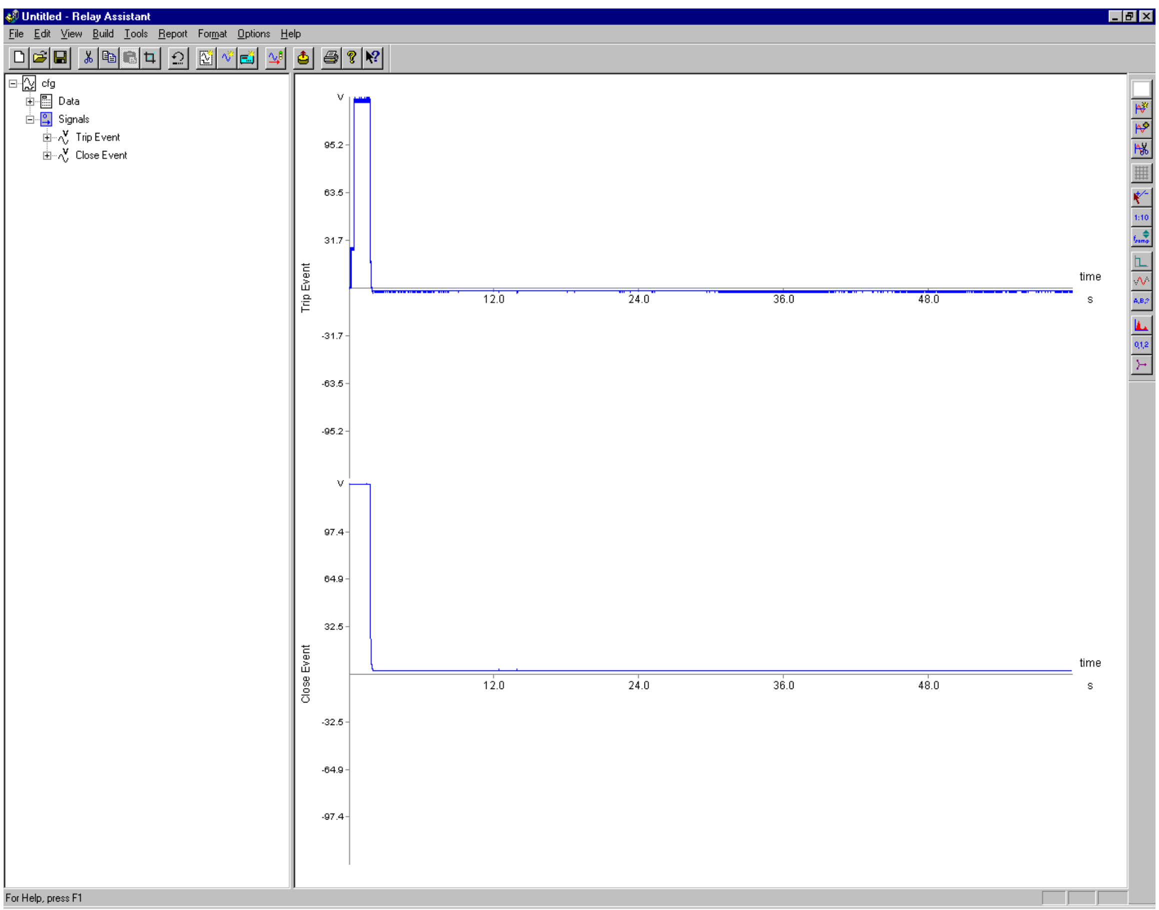


Figure 4-7: Waveforms of “Trip Event” and “Close Event” signals recorded by Data Acquisition Unit

Signals recorded by DAU were lasting 1 min. In Figures 4-8 and 4-9 only 4 seconds of both channels are shown.

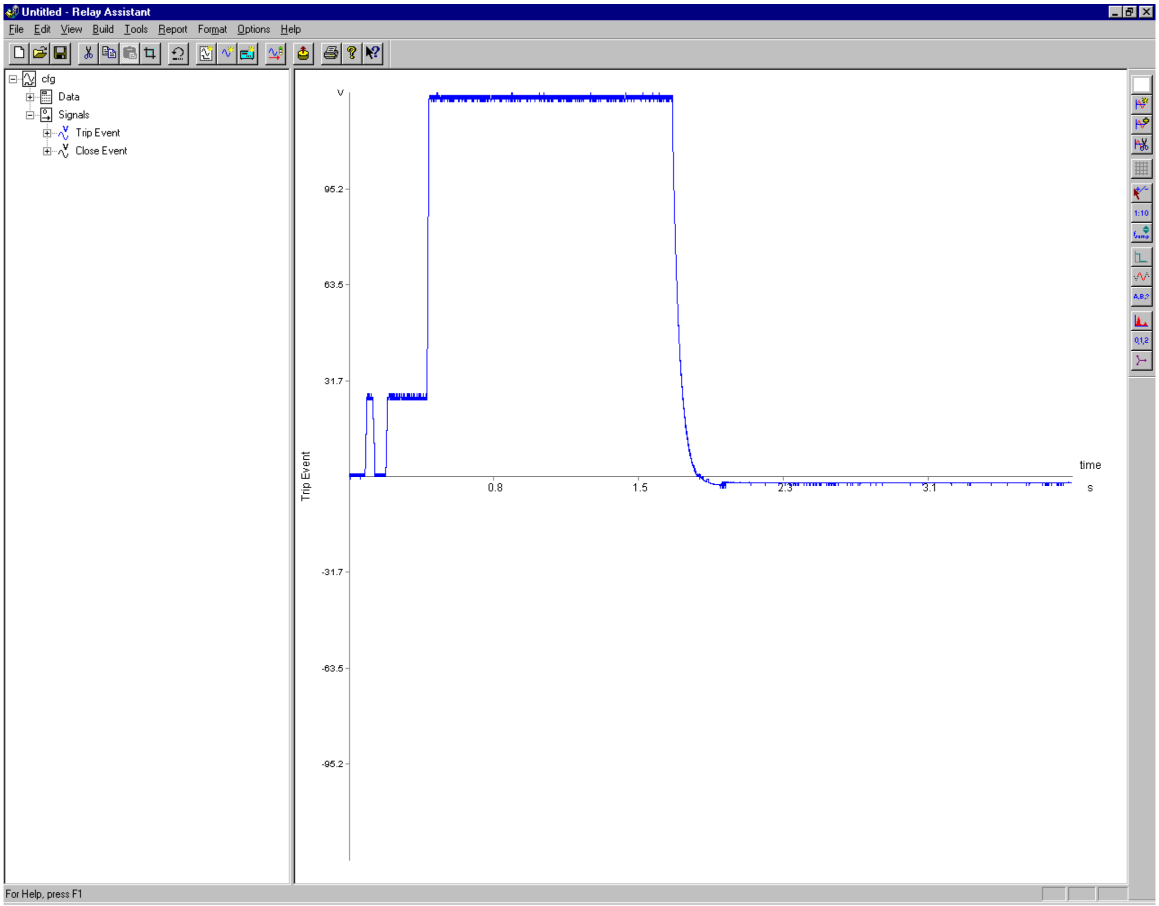


Figure 4-8: Waveform of "Trip Event" signal recorded by Data Acquisition Unit

As it can be seen, the waveform matches the "Trip Event" signal captured by the oscilloscope. There is approximately 0.5 seconds of "Trip Event" signal waveform recorded before the tripping takes place. Since the signal is reproduced according to the configuration and data files, voltage level is 130V, even though voltage level of the recorded signal was 5V. That is because the gain of 26 is written in the configuration file (during signal conditioning the signal level was lowered from 130 to 5V)

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In Figure 4-9, the "Close Event" signal is shown. Obviously, voltage level of the signal was 5V (130V at circuit breaker) when the tripping occured. Transition from 0 to 5V wasn't recorded because only 0.5 seconds before tripping were recorded and transition happened around 0.2 seconds before that.

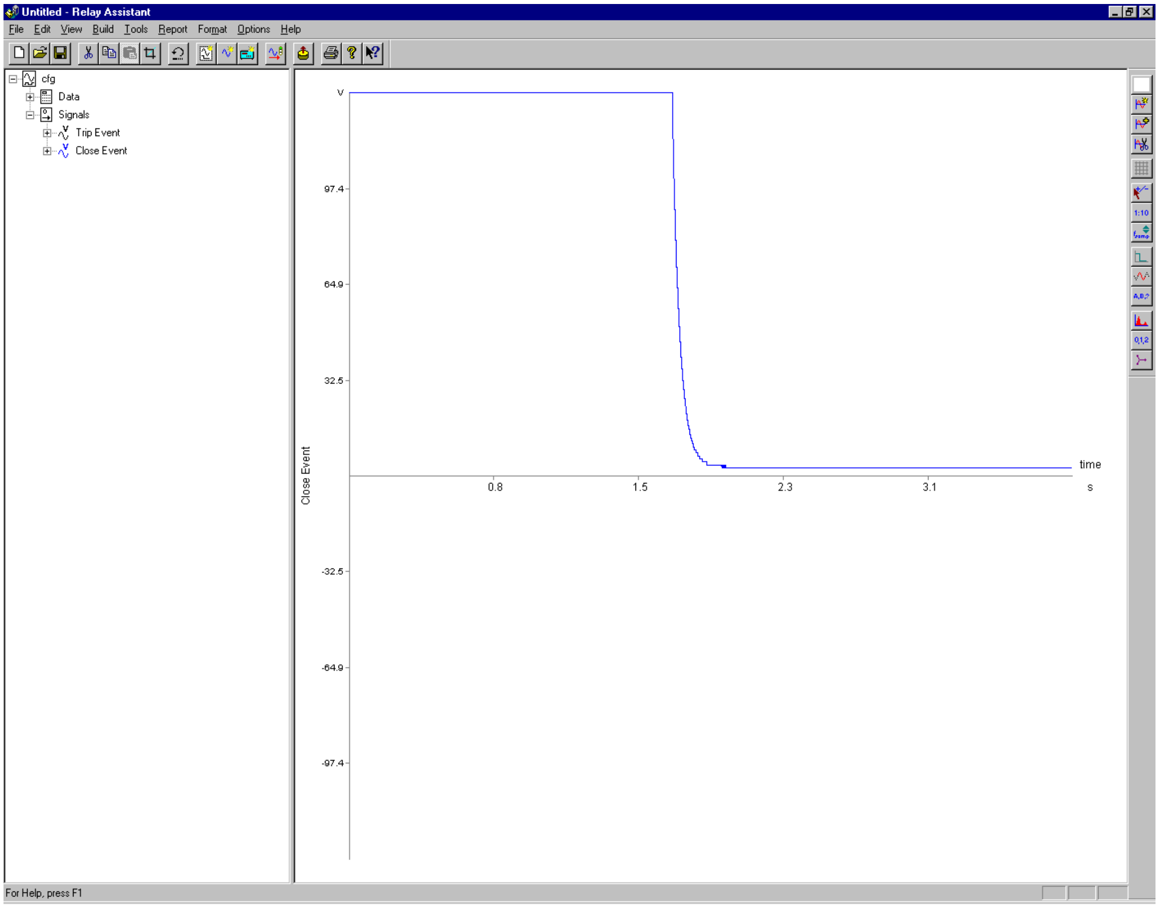


Figure 4-9: Waveform of "Close Event" signal recorded by Data Acquisition Unit

What can also be noticed is that voltage level of "Close Event" signal is stuck at 5V. If we pay a little bit more attention to Figure 4-6 (channel 3) we can realize that voltage level of signal is around 5.3V. Since the input signal voltage range of the acquisition board is adjusted at (-5,+5)V, any signal with the level higher than 5V is sampled as 5V level signal.

This problem can be solved with finer adjustment of the board for signal conditioning. There is a potentiometer onboard, which should assure that the output signal level is within 5V. That fact was neglected prior to the testing and that is the reason why the signal with voltage level higher than 5V appeared. So, with proper adjustment of the hardware, system works correctly, which is obvious as the waveform of "Trip Event" signal is observed.

4.2 Field testing

This activity will be completed in the next phase of the project.

5. SYSTEM ASSEMBLING AND MOUNTING

5.1 System components and housing

Two metal boxes, received from Center Point Energy, are supposed to be a housing for all the system modules. Boxes have shape like in Figure 5-1:

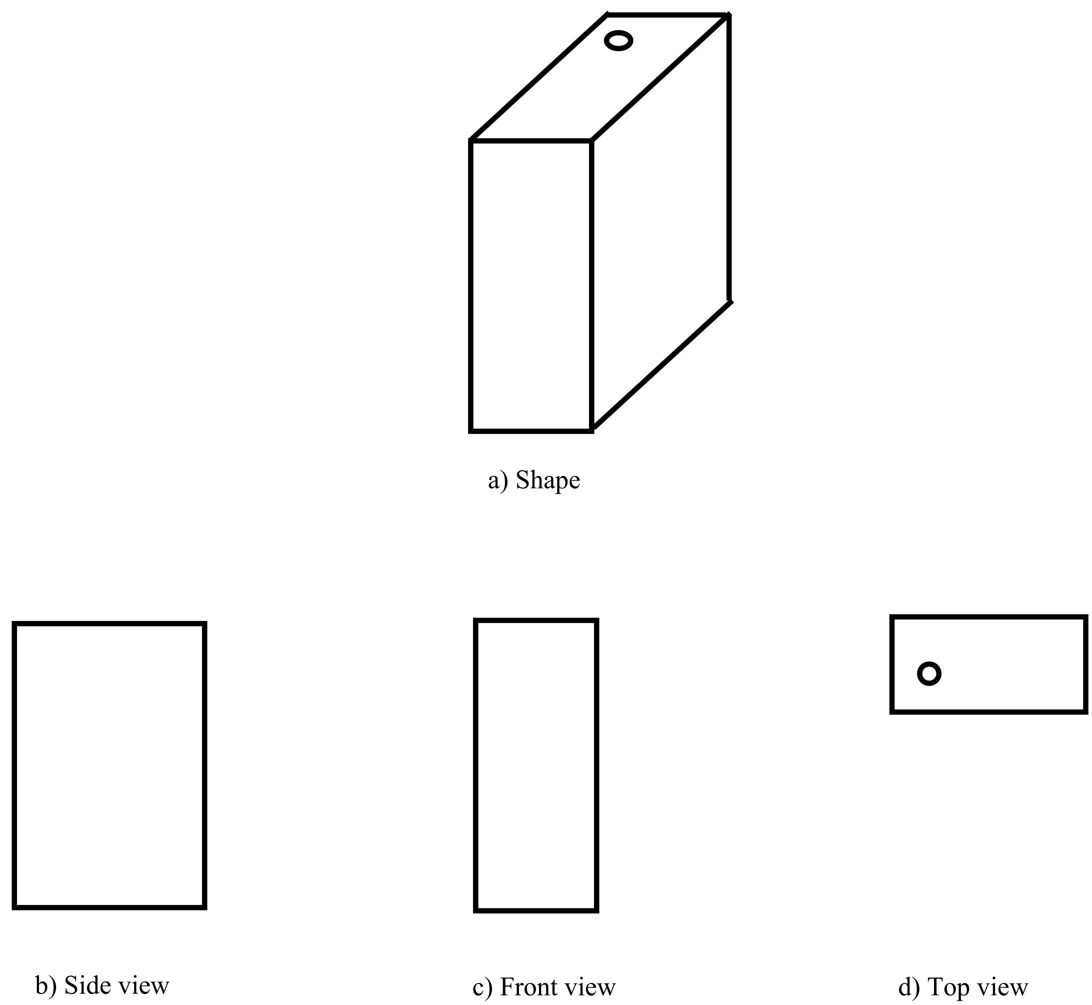


Figure 5-1: Metal box for housing

The hole at the upper side of the box is for antenna, which should be outside of the box in order to provide better communication with the receiving modem.

Part of the unit, which resides near circuit breaker, consists of two power supplies, Prometheus PC104 board (processor with data acquisition), board for signal conditioning and galvanic isolation, and wireless modem (with its power supply). Two power supplies are necessary because we need to separate the supply for both high and low voltage side of the circuit for galvanic isolation. As a power supply, the standard PC power supply was used (Figure 5-2).

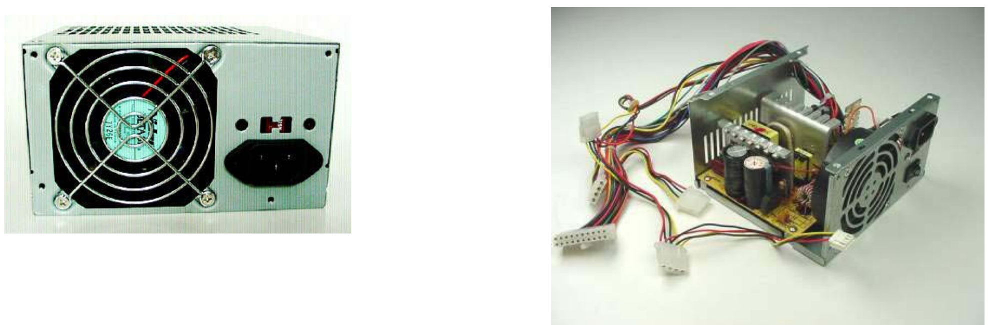


Figure 5-2: PC Power supply

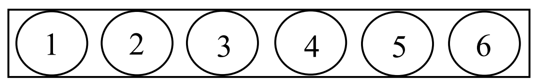
First one provided only the ground, 12V and –12V for high voltage side (before signal conditioning and galvanic isolation). The other provided ground, 12V, -12V for low voltage side, along with ground and 5V needed for power supply of the PC104 processor board.

Part of the unit residing near concentrator PC consists only of a wireless modem (together with its power supply). It should be connected via RS232 cable to the concentrator PC.

5.2 Wiring and assembling

First of all, power supply has to be provided for both PC104 board and board for conditioning and isolation.

Power connector at the isolation board has 6 pins and pin assignment is:

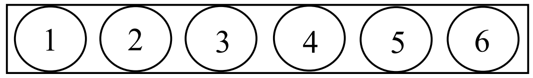


1 ... Gnd1
2 ... $-V_{cc2}$
3 ... $+V_{cc2}$
4 ... Gnd2
5 ... $-V_{cc1}$
6 ... $+V_{cc1}$

Figure 5-3: Power connector with pin assignments

The Numeration 1 is for low voltage side (after galvanic isolation), and 2 is for high voltage side (before conditioning and isolation). Voltage level is 12V for both Vcc. Three of them are connected to the first power supply (pins 1, 5 and 6), while the other three are connected to the second power supply (pins 2, 3 and 4).

Connector for input signals from circuit breaker is the same and pin assignments are shown in Figure 5-4. Since there are only two available channels, only two input signals are acceptable. Each input signal has two wires: positive and negative end. Output signals (pins 3 and for) are voltages referenced to Gnd1 from Figure 5-3. Since signal conditioning and galvanic isolation are performed, these signals can be directly wired to 50 pin connector (connector for data acquisition) on PC104 board, along with ground signal. Voltage drop between each output signal and ground cannot exceed 5 V (-5 V).



1 ... $+In_1$
2 ... $–In_2$
3 ... Out_1
4 ... Out_2
5 ... $–In_2$
6 ... $+In_2$

Figure 5-4: Signal connector with pin assignment

Ground1 from Figure 5-3, is connected to pin AGND (Analog ground) on 50 pin Data Acquisition connector of PC104 board. Two output signals are wired to Analog input 12 and Analog input 11. The reason for that is simple. We have 11 analog signals from circuit breaker, which we are not able to monitor because we have only two channels for signal conditioning and galvanic isolation. Since status signals Trip Event and Close Event have to be monitored, there is no room for any other analog signals from circuit breaker. 11 Analog signals are from Analog input 0 to Analog input 10. First two status signals are Trip Event and Close Event and they are assigned to Analog Input 11 and Analog input 12, respectively.

PC104 board requires 5V power supply and it is provided from one of the PC power supplies used for supplying board for conditioning and isolation.

Finally, wireless modem has to be connected to antenna and processor board through RS232 interface. One of the metal boxes contained antenna adapter, which connects antenna with wireless modem and allows antenna to be located outside the box, while modem can be located anywhere in the box. That box is used as housing for DAU part residing near circuit breaker. Other part of DAU residing near concentrator PC requires only wireless modem in the box with plenty of space available. In that box, the modem and antenna are connected directly through the hole at the top of the box.

5.3 DAU outlook

After wiring, two more tasks had to be completed. First was to make holes for screws necessary for attaching modules to the metal box. The other was to cut a metal box, so coolers of power supplies can be outside the box. Also, some wires (AC input for power supplies, input signals from circuit breaker) had to be located partly outside of the box and that is another reason why boxes had to be cut at certain locations. Outlook of the DAU, after everything was done, is shown in Figures 5-6, 5-7 and 5-8.

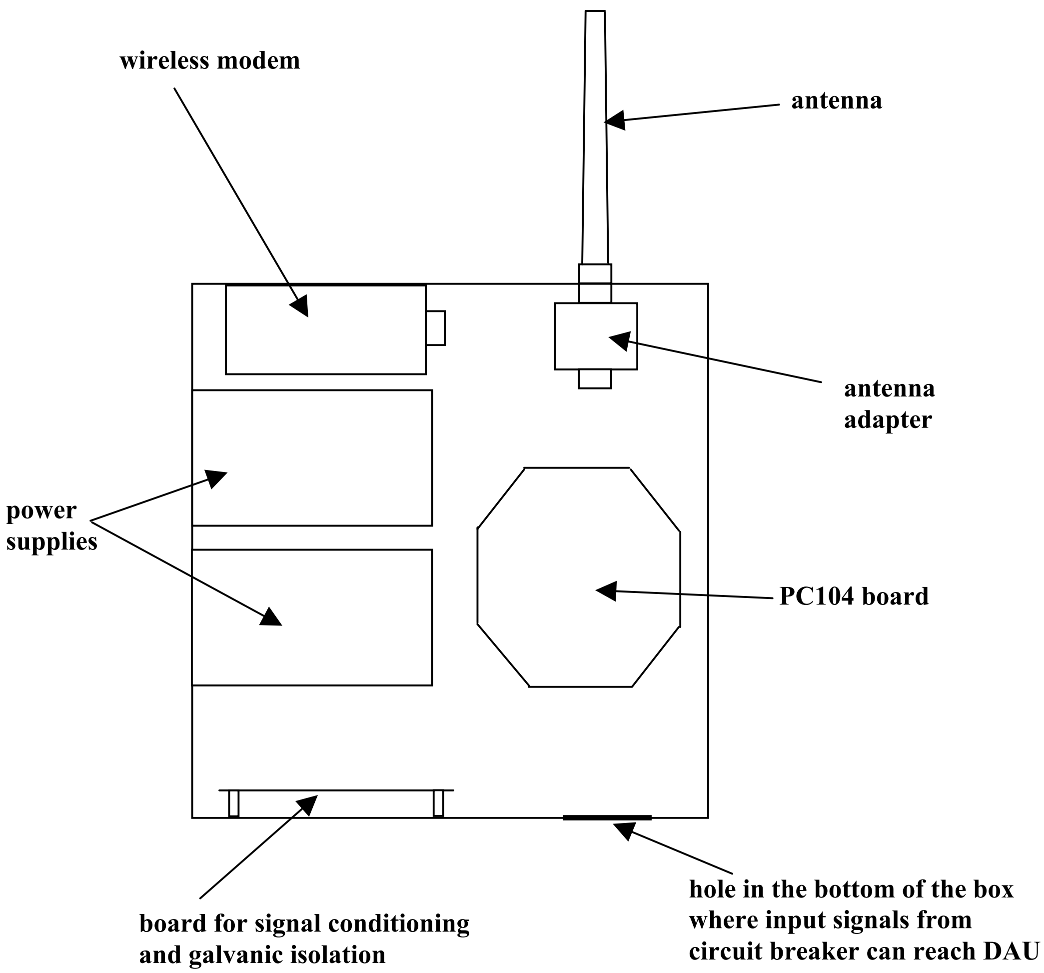


Figure 5-5: DAU (Side view)

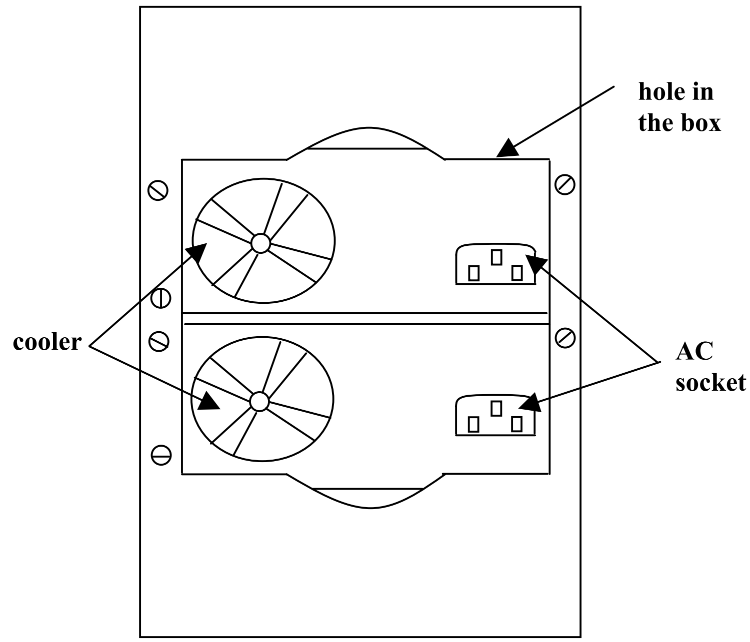


Figure 5-6: DAU (Rear view)

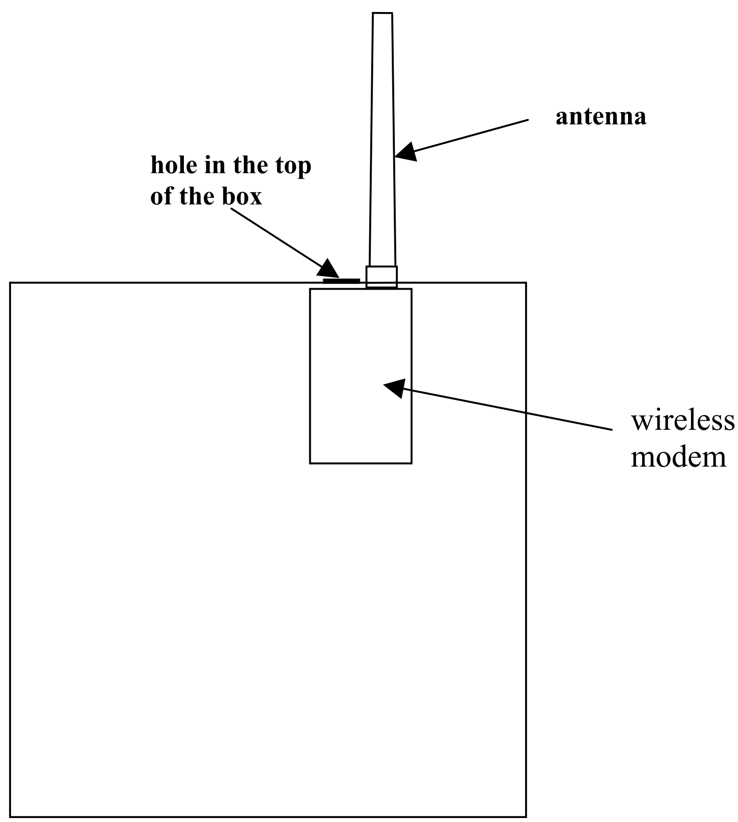


Figure 5-7: Part of DAU residing near concentrator PC

From the rear view shown in Figure 5-7, the coolers of power supplies can be noticed because of the holes made in the box.

In Figure 5-8 second part of DAU is shown. It doesn't have so many components inside, only wireless modem, while antenna is out of the box. There are also holes at the top of the box which allow power supply for the modem and RS232 cable to reach the modem.

Note: Although DAU would work with PC power supplies, after testing, we decided not to use them. Reason for that is the fact that PC power supplies are not isolated one from another, so even though we have power lines for two separate power supplies on our SCI module, the real isolation is not performed. From that point, for further testing, two power supplies (T-60C and T-40C from Mean Well [3]) with output of $\pm 15V$ (2A,1.5A) were used as a power supplies. Outlook of DAU after mounting and wiring is shown in Figure 5-8:

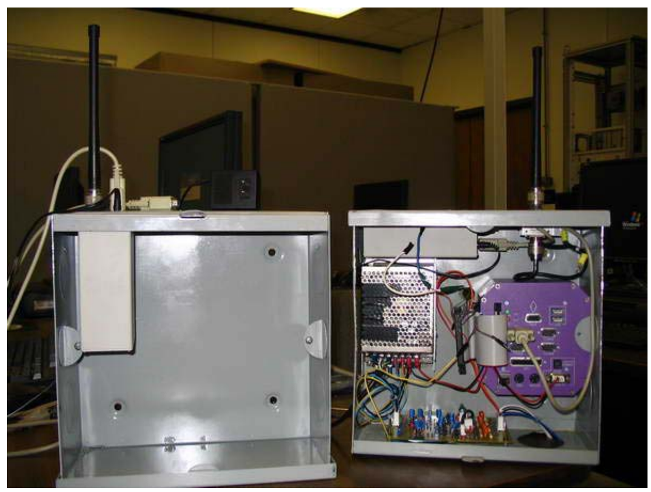


Figure 5-8: DAU outlook

[3] Datasheet can be found in a catalog